Parameterizations Developed With ARM Support Which Improve Climate Models

A central goal of the ARM program is to improve the cloud and radiation physics in climate models so that society may have increased confidence in their climate change projections. For much of the first 15 years of the program, ARM focused on the establishment of a continuous observing capability at its fixed sites and developing robust retrieval algorithms that convert the raw instrument measurements into geophysical quantities useful for climate modelers. Naturally, the improvement of climate models as assisted by ARM data would be delayed and come later in the life cycle of the program. However, within the last 5 years, a sizeable number of parameterizations, developed in part with ARM funding, have been tested in climate models. Furthermore, many parameterizations have led to model improvements significant enough that climate modelers would choose to adopt them as part of their base climate model. Below is a list of ARM-sponsored parameterizations that have either been tested in or tested and incorporated into climate models.

Note that the list also includes parameterizations that have been tested in weather prediction or regional models. These models also have cloud and radiation parameterizations that need improvement and are very similar to climate models except for typically operating at finer spatial scales.

It is important to recognize that many of these parameterizations require 5 or more years to develop and so it is quite common that other research agencies also contributed to the sponsorship. **Therefore, ARM cannot claim sole credit for their development**. In most cases, the organization that primarily sponsors each climate model also contributed resources which led to the successful implementation of the parameterization into their base model. Occasionally, the ARM support might have been a relatively small contribution to the total effort.

Below is a list of the ARM-sponsored parameterizations which have either been incorporated, are likely to be incorporated, or have been tested with promising results in climate, weather or regional models. The status of each parameterization is indicated by *** for “incorporated”, ** for “likely to be incorporated in the next few years”, and * “tested with promising results”. For more information on each of these items, you may wish to use the hyperlinks. The hyperlinks take you to an ARM research highlight if available, and otherwise a journal article or similar documentation.

1. *** RRTMG. ARM has supported the development and testing of the Rapid Radiative Transfer Model (RRTM). The model has been extensively tested against ARM data and is considered to be a premier radiative transfer model. The model exists in a reduced form for climate and weather models and has been incorporated in many models. Models that have incorporated RRTMG into their base model include the ECHAM5 climate model (LW only), the ECMWF and NCEP (LW only) weather prediction models, and the WRF (LW only), MM5 (LW only) and ARCSyM (LW only) regional models. Models that are testing

RRTMG include the CAM and GFDL climate models. RRTMG is likely to be incorporated into the CAM in the next few years.

2. *** The Monte Carlo Independent Column Approximation (McICA) is a technique which allows for more accurate treatment of the radiative properties of clouds. Using a set of random numbers (i.e. a Monte Carlo technique), it pairs a random cloud profile with a random wavelength to treat the non-linear relationships between clouds and radiation. The technique is implemented in the in ECMWF weather prediction model and is in an advanced stage of testing in the CCSM and GFDL climate models. When implemented into the ECMWF model, marked improvements in the distribution of tropical precipitation occurred.
3. *** A New Deep Convection Closure Parameterization. Working with ARM data, Shaocheng Xie and Minghua Zhang developed a new way to determine when deep convection should happen in a model and by how much when it occurs. Instead of relying solely on convective instability, the new parameterization relates the occurrence and magnitude of deep convection to the rate at which the large-scale circulation destabilizes the atmosphere. This new parameterization reduces the frequency of deep convection but increases the intensity of convection when it occurs. Both of these changes ameliorate common climate model biases. This parameterization was demonstrated to yield improved climate simulations in the CAM and has recently been incorporated into the weather prediction model of the Japanese Meteorological Agency (JMA).
4. *** A New Stratiform Cloud Condensation Parameterization. Where and when clouds form are among the most important matters for a climate model to predict correctly. Building on earlier work, Minghua Zhang and collaborators developed an improved representation of the manner in which large-scale or stratiform clouds form. The parameterization simultaneously predicts the total amount of water condensed as well as the fraction of the grid-box in which the clouds form. The parameterization was implemented into the second version of the CAM.
5. ** New Parameterizations of Aerosol-Cloud Interactions. The indirect effect of aerosols on clouds is thought to be an important forcing agent for global climate. The representation of aerosol-cloud interactions in climate models have been significantly advanced due to the efforts of Steve Ghan (PNNL) and others. Steve Ghan was among the first to test a prognostic representation of cloud droplet number in a climate model. Xioahong Liu (PNNL), Joyce Penner (U. Mich), and Steve Ghan have expanded this to ice clouds by adding a prognostic treatment for ice crystal number and a new parameterization for ice nucleation. These parameterizations have worked well when implement into the CAM, and compare well against ARM measurements of mixed-phase clouds from the M-PACE experiment at the North Slope of Alaska. These parameterizations are now being combined with other treatments of aerosol-cloud interactions that are likely to be included into the next release of the CAM.
6. ** A Parameterization of Vertical Velocities in Deep Convection. The intensity of moist convection is an important diagnostic of climate change not currently predicted by most climate models. Anthony Del Genio (GISS) and his collaborators tested a previously developed parameterization which when implemented into the GISS climate model was able to reproduce the common

observation that deep convection is more intense over land than over ocean. While the model predicts little change in the intensity of deep convection with global warming, the intensity of the strongest storms does increase. The parameterization is being refined based upon ARM observations from the Tropical Warm Pool – International Cloud Experiment.

7. ** A New Surface Albedo Parameterization. Fanglin Yang, an ARM fellow at NCEP, developed an improved parameterization of surface albedo for the NCEP weather prediction model. The new parameterization was based upon ARM observations which showed that the albedo for the direct solar beam could well be parameterized as a function of the solar zenith angle, independent of the land surface type.
8. ** New Shallow Convection and Boundary Layer Turbulence Parameterizations. Chris Bretherton (U. Washington) and his associates have developed new shallow cumulus and moist turbulence parameterizations. The purpose of these new parameterizations is to improve the simulation of marine boundary layer clouds which are a major source of uncertainty in climate model projections of the magnitude of the climate change. These parameterizations are likely to be a component of the next version of the CAM in which improved marine boundary layer cloud simulations were demonstrated. In addition, the shallow convection parameterization is also likely to be incorporated into the next version of the GFDL climate model.
9. ** A New Shallow Convection Parameterization. Roel Neggers, an ARM fellow at ECMWF, developed a new way to treat shallow convection for the ECMWF weather forecast model. The new parameterization, known as the "dual-Mass-Flux" parameterization, has an explicitly coupling with the parameterization of boundary layer turbulence. With this coupling, the source air for shallow convection in the boundary layer and its evolution up through an updraft in the cumulus clouds is explicitly modeled with a single mass-flux plume. This new parameterization, likely to be incorporated soon into the model, yielded a dramatic improvement in simulations of shallow cumulus clouds over land when compared to ARM observations from the Southern Great Plains site. This remedied the problem earlier diagnosed by the ARM fellow Sylvain Cheinet.
10. ** New Parameterizations of Ice Microphysics. Dave Mitchell (DRI) and colleagues have been studying ways to represent the size distribution, radiative properties, and fall speeds of ice crystals. Working with the CAM, they demonstrated how their parameterizations could have a significant impact on the simulated amounts of ice in the upper tropical troposphere as well as the air temperatures at these levels. It is anticipated that the ice fall speed and optical property schemes will be included in the next version of the CAM.
11. * A Parameterization Linking Boundary Layer Turbulence and Shallow Clouds. Larry Berg (PNNL) and others have been working on a new way to couple shallow clouds to boundary-layer turbulence. This parameterization uses joint probability density functions of temperature and humidity to represent the sub-grid variability of these variables and to provide realistic perturbation values to the cumulus parameterization used in the host model. This scheme has undergone initial testing and is being implemented in WRF.

12. * A New Parameterization for Deep Convection Closure. As discussed in item #3 above, the way in which climate models parameterize the conditions for and intensity of deep convection are extremely important. Based on analysis of data from ARM and other field campaigns, Guang Zhang derived a new parameterization for the conditions of deep convection. Similar to the parameterization of Shaocheng Xie and Minghua Zhang, it parameterizes deep convection in terms of the rate at which the large-scale circulation destabilizes the atmosphere. When tested in the CAM, the new parameterization improved the simulation of response of tropical convection to El Nino as well as reduced the "double-ITCZ" problem which occurs when the CAM is coupled interactively to an ocean model.

Note that there are other promising parameterization ideas developed with ARM funding which await testing in climate models. These includes those related to cloud overlap , the rate at which clouds produce rain which is known as autoconversion, and the way to better predict cloud fraction using a statistical cloud scheme.

Sometime progress is made when ARM identifies that further parameterization exploration is unneeded. This happened when the analysis of some observations indicated the possibility that clouds absorb much more solar radiation than radiative transfer models calculate. ARM mounted a major field campaign (ARESE) that demonstrated that if there is anomalous shortwave absorption anomaly, that its magnitude is much smaller than first thought. More recent ARM work also supports the conclusion that it is likely that there is no shortwave absorption anomaly that models would need to be concerned with.